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SPECIFICS OF GLASS MELT CONVECTION ACROSS THE MELTING TANK FOR SHEET GLASS

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The conditions and the mechanism of glass melt migration in wide melting tanks for sheet glass are investigated for different types of melting zone charts: symmetric and asymmetric arrangement of batch heaps on the glass melt surface.

The method of launching indicators provides big opportunities for studying glass melt convection in tank furnaces [1]. This method made it possible to obtain data on the speed of propagation of freshly melted glass inside a tank, and furthermore, the homogenizing capacity of the furnace and its specific zones could be estimated. Sufficient data on the main regularities of glass melt convection were accumulated, whereas the particulars of this process are yet insufficiently studied. In modeling this process, it is difficult to investigate the distinctions in the glass melt which is migrating along the tank, when the melt surface charts in the melting zone are different. It appears expedient to expand this research and clarify, for instance, the reasons for nonuniform distribution of defects and the differences in the degree of chemical homogeneity across glass melt bands.

The present study is dedicated to studying the specifics of the migration of an indicator in wide glassmelters for sheet glass[2] under different conditions of the melt surface in the melting zone, i.e., symmetric divergence of batch heaps and melting froth toward the lateral zones of the tank, and their asymmetric shift towards one side of the furnace.

In order to better distinguish glass flows along the tank sides, in the experiments, the batch marked by the indicator was charged through the pairs of chargers: central chargers and lateral chargers (central and lateral launching of the indicator).

The experimental procedure was described earlier [1]. It remained unchanged in all subsequent experiments.

The following parameters were used to characterize the differences in the conditions of exit of the indicator from the glass-melting tank:

– the time of arrival of the first batch of marked glass melt to various sections across the tank length;

– the time of the indicator concentration growth and decrease;

– the maximum concentration of the indicator in glass samples from the considered tank sections;

– the overall duration of the indicator staying in the tank.

The glass melt samples were taken along the entire tank length via the peepholes between the burners, as well as from the middle and the corners of the charging hopper. The main parameters of the studied glassmelters are given in Table 1, whereas the summarized research data characterizing the conditions of the indicator migration in different furnace zones are given in Table 2 (since in the industrial conditions, the number of lateral sections in which samples were taken

TABLE 1

Parameter	Type of melting zone with respect to the tank longitudinal axis	
	symmetrical	asymmetrical
Output, tons/day	300	260
Surface area, m^2:		
total	589	615
heated part	265	268
Melting tank size, m:		
length	32.8	29
width	10	9
Specific glass melt output per heated surface, kg/m^2 per day	1132	970

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TABLE 2

Mass transfer parameters	Glass melt sampling sites	Conditions of introducing indicator into the tank*				
		symmetrical melting zone			asymmetrical melting zone	
		via all chargers	via two central chargers	via two lateral chargers	via all chargers	via two lateral chargers
Time of detecting the indicator since its launching, h	In the charging hopper	1.5	1.0	1.5/2.5	1.0	0.5
	Between burners 3 and 4	4.0	3.0/4.0	2.0/11.5	2.0/1.5	2.0/3.0
	Between burners 4 and 5	3.5/5.5	4.5/5.5	3.0/3.5	2.0/2.0	2.0/4.0
	Beyond burner 7	3.5/3.5	6.0/6.5	4.8/8.5	4.5/17.0	5.0/17.0
	In the end of the chilling zone	7.0/8.0	8.0/7.5	6.0/7.5	–	–
Speed of migration of the first batch of indicator to the given section, m/h	In the charging hopper	–	–	–	–	–
	Between burners 3 and 4	3.2	4.2/3.2	6.3/1.1	4.7/6.2	4.7/3.1
	Between burners 4 and 5	4.7/2.9	3.6/2.9	5.5/4.6	6.3/6.3	5.1/3.2
	Beyond burner 7	7.6/7.6	4.5/4.1	6.5/3.1	8.5/21.8	7.6/22.4
	In the end of the chilling zone	8.7/7.5	7.5/8.0	10.0/8.0	–	–
Time of indicator concentration rising to the maximum value, h	In the charging hopper	1.0	2.0	3.5/9.5	4.0	3.0
	Between burners 3 and 4	5.0/6.0	14.0/13.0	3.5/31.0	2.0/1.5	2.5/3.5
	Between burners 4 and 5	1.0/9.0	14.0	4.5/42.0	3.0/15.5	2.6/6.0
	Beyond burner 7	7.0/3.0	11.5/15.0	5.0/24.0	17.5/45.0	9.0/24.0
	In the end of the chilling zone	6.0/9.0	16.0/17.0	7.0/24.0	–	–
Duration of producing glass melt containing the maximum amount of indicator, h	In the charging hopper	6.0	9.0	15.0/35.0	38.0	17.0
	Between burners 3 and 4	8.0	34.0/53.0	7.0/40.0	5.0/4.0	5.0/4.0
	Between burners 4 and 5	27.0/39.0	54.0/52.0	11.0/54.0	3.5/15.0	5.6/6.0
	Beyond burner 7	52.0/66.0	54.0/51.0	4.0/24.0	26.0/26.0	12.0/15.0
	In the end of the chilling zone	33.0/40.0	56.0/66.0	16.0/24.0	–	–
Maximum concentration of indicator, %	In the charging hopper	0.06	0.06	0.03/0.01	0.3	0.025
	Between burners 3 and 4	0.04	0.009	0.04/0.004	0.3/0.3	0.3/0.3
	Between burners 4 and 5	0.027/0.023	0.009	0.04/0.004	0.3/0.25	0.3/0.03
	Beyond burner 7	0.029/0.02	0.009	0.04/0.006	0.04/0.035	0.03/0.02
	In the end of the chilling zone	0.033/0.03	0.01/0.009	0.03/0.009	–	–
Time of complete removal of indicator from the given section, h	In the charging hopper	582	514	805/835	134	190
	Between burners 3 and 4	535/528	440/500	780/840	47/80	24/128
	Between burners 4 and 5	553/595	530/500	805/840	100/350	38/153
	Beyond burner 7	880/790	710/830	800/840	466/620	380/480
	In the end of the chilling zone	575/580	600/707	840/840	–	–

* Two values characterize the mass transfer on the tank sides: the value above the line) the indicator launching side; below the line) the opposite tank side.

was not always the same, due to the wear of the brickwork in peepholes, certain columns in Table 2 have blank spaces).

The first results of launching the indicator demonstrated that for a furnace with a symmetrical melting zone, when the marked batch is loaded through all charging hoppers, the nature of mass transfer, especially the speed of arrival of the first marked batches to the section under consideration, is similar for both sides of the tank. This suggests that the glass melt migration with respect to the longitudinal axis of the furnace is sufficiently symmetrical. The obtained data served as the basis for further analysis, which was carried out by correlating the results of the central and lateral launchings of the indicator.

An analysis of the marked melt samples from the charging hopper demonstrated that the distinguishing features of the central launching of the indicator consist of a higher concentration of the indicator and its faster removal from this zone of the tank, as compared to the lateral launching.

In addition to the data specified in Table 2 it was found that in the lateral launching of the indicator, only an insignificant amount of the tagged glass melt penetrates into the center of the charging hopper and its opposite corner.

The analysis of glass samples taken from the charging hopper center in any variant of introduction shows as well that as the freshly melted glass containing the indicator circulates in the charging cycle, the periods of a high concentration of the indicator alternate with periods when the indicator concentration decreases or is absent. This phenomenon is observed only in samples taken from the middle of the charging hopper. Such behavior of the indicator was not observed in the hopper corners.

In the case of central launching of the indicator, the section between burners 3 and 4 exhibits sufficient mass transfer symmetry on both sides of the tank, a very low maximum concentration of the indicator, and a fast removal of the indicator from this section. In lateral launching, complete asymmetry in mass transfer was observed, i.e., the indicator was registered on the same side from which it had been loaded into the tank, several hours earlier than on the opposite side,

and its concentration was significantly higher. When the indicator concentration started declining on the launching side, it started growing on the other side of the furnace. This is evidence of the fact that the newly melted tagged glass at first spreads over the glass melt surface mainly on the same side from which the batch with the indicator was charged into the tank. It reaches the other side only after some circulation in the charging cycle, which is corroborated by the delayed appearance of the indicator on the other side of the tank and the differences in the indicator concentration and the total duration of its stay in the tank. All this points to the difference in the time of glass melt lateral circulation in this portion of the furnace.

The above listed mass transfer peculiarities are mostly preserved in the section between burners 4 and 5. In particular, within the first 40 h after lateral launching, as distinct from central launching, the concentration of the indicator in samples taken on the side of launching dropped from 0.1 to 0.008%. Such dynamics is possible when part of the tagged glass melt migrates to the other side of the furnace.

The time of the full removal of the indicator from the charging zone is shorter in the case of launching the indicator via central chargers than in the case of lateral chargers. The registered difference in the rate of indicator removal from samples of this zone shows that this zone has complex migration routes of newly formed melt in the charging cycle, which increase the intensity of glass melt circulation in the tank zone adjacent to the wall.

All the above listed regularities are registered as well in the section beyond the last burner, i.e., as distinct from central launching of the indictor, in the case of its lateral launching, a delay in the time of indicator arrival to the opposite side of the tank is observed as well.

It is interesting that the indicator arrived to the section beyond the last burner at the same velocity as to the section between burners 3 and 4. This is evidence of the fan-type propagation of the indicator along the tank, as the consequence of which the melt arriving to the last burner section does not represent the lateral flows of the tagged melt migrating to the last burner from the sections between burners 4 and 5 along the melting tank wall in parallel to the tank axis, but consists of central melt flows propagating at an angle to the longitudinal axis and having a slightly higher velocity.

The time of the indicator arrival to the section behind the last burner on the side opposite to the launching side in this experiment was shorter than the time of arrival to the section between burners 3 and 4. Therefore, it follows that on the specified side on the tank, the indicator penetrated into deeper layers of the charging cycle near the refractory walls of the tank, was entrained by the bottom flows to the quelpunkt, penetrated to the surface layers of the axial part of the tank, and moved toward the last burners at an angle to the longitudinal axis.

In central launching, the average concentration of the indicator in the samples taken beyond the last burner proved to be equal on both sides of the tank, as in the preceding sections. At the same time, in lateral launching, the main part of the melt bearing the indicator was observed on the side from which the tagged batch was introduced. As the indicator concentration on this side decreases in the section behind the last burner, the concentration on the opposite side increases. The total duration of the stay of the tagged glass melt behind the last burner is shorter in central launching than in lateral launching, which is another evidence of the additional circulation of the glass melt made from the batch loaded through the lateral chargers.

The specified regularities are preserved at the end of the chilling zone. Thus, in central launching, the indicator arrives to the end of the chilling zone simultaneously on both sides of the tank. In lateral launching, a delay in the arrival of the indicator to this section on the opposite side of the tank was registered, although not so significant as between burners 3 and 4. Since the indicator arrives to the chilling zone end with a higher speed in the case of lateral launching, it can be assumed that the indicator is entrained in this zone not by the longitudinal flow passing past the last burner, but by the central flow moving along the fan-shaped route at an angle to the longitudinal axis of the tank and having an elevated speed. This regularity is preserved in both types of indicator launching. At the same time, the differences in the indicator concentration on different sides of the tank both in lateral and in central launching remain the same as in the area behind the last burner.

The high speed of the glass melt arrival to the last burner and to the chilling zone demonstrates that in a wide tank, due to highly developed lateral convection, the tagged glass melt propagates at an angle to the longitudinal axis of the tank. Only such a direction of flow could lead to a fast arrival of the tagged melt to the end of the melting zone and to the chilling zone.

It is notable that under lateral launching, the speed of the indicator arrival to the area between burners 3 and 4 was lower than the speed of arrival to other, more distant sections of the tank. This suggests that indicator introduced to the tank zone near the wall is not carried by direct flow in the surface melt layers. In all the subsequent tank sections, the indicator from the glass melt is entrained by descending flows near the tank walls. Next, these flows ascend to the quelpunkt and propagate in a fan-type way along the tank at an angle to the longitudinal axis.

Comparing the duration and the speed of propagation of tagged glass melt in the considered tank with other melting tanks in which an indicator was launched [2 – 5], it can be stated that the speed is higher in the float glass tank. The reasons could be the higher output of this tank and the high temperature of glass melting.

Let us study the results of studying the conditions of the migration of the indicator in the tank with the asymmetric arrangement of the melting batch in the melting zone. Two experiments were performed: 1) launching the indicator through all chargers, and 2) through two lateral chargers on the side with a more extended melting zone (Tables 1 and 2).

The specifics of the obtained data are as follows.

In spite of the one-sided launching, part of the indicator migrated to the opposite side of the charging hopper and was present in glass samples taken in that area for a long time. This means that newly melted tagged glass spreads from the batch heaps across the entire width of the tank. The tagged glass melt on the side of an indicator launching penetrates into the charging cycle due to its immersion in inner melt layers under the effect of convection existing near the wall and then keeps circulating in the charging cycle, gradually migrating to the opposite side of the tank.

The asymmetry of the melting batch position in the section between burners 3 and 4 in the melting zone and, accordingly, the asymmetry of the whole charging cycle [2] result in differences in the time of registering the indicator at different sides of the tank and other mass exchange parameters in this zone.

The sequence of the emergence of the indicator in the section between burners 3 and 4 in two variants of its introduction indicates that on the tank side with the extended melting zone, the first batch of the indicator quickly penetrates into the charging cycle under the effect of lateral convection. Its shift with respect to the longitudinal axis resulted in the fact that the indicator entrained in ascending flows to the quelpunkt was mainly carried to the opposite side of the tank, where the melting zone was shortened, which led to the longer presence of the indicator in the samples taken on that side of the furnace. In particular, in spite of the one-sided charging of the tagged batch, the time of arrival of the indicator to the section between burners 3 and 4 and its maximum concentration proved to be equal or similar at both sides of the tank. This is evidence of strong lateral convection, which levels the differences caused by different conditions of indicator launching.

The freshly made melt does not arrive simultaneously across the section between burners 4 and 5. It first reaches the specified section on the side with the longer melting zone and higher concentration of the indicator. This suggests that in the asymmetrical melting zone, the fresh glass migrates along the extended melting side, over the quelpunkt, and arrives to the working melt flow without averaging.

Of special interest is the significant difference in the mass transfer parameters observed on the sides of the tank in the sections between burners 3 – 4 and 4 – 5 in lateral launching of the indicator. For instance, the glass melt on the side of the shorter melting zone arrives to the section between burners 3 and 4 with a high indicator concentration and to the section between burners 4 and 5 with a significantly lower concentration. This suggests that glass melted from the batch loaded through the lateral chargers on the side with the extended melting zone is carried by convection flows to the opposite side only up to the section between burners 3 and 4. The melt arriving to the section between burners 4 and 5 is the melt that has stayed longer in the tank and, accordingly, is more averaged. This is confirmed by the almost double increase in the length of staying of the indicator in this zone of the tank. Such distinction was not registered on the extended melting zone side.

The observed peculiarities in the behavior of the indicator in the first half of the melting tank, including the quelpunkt, suggest that when the indicator is launched through all chargers, the glass melted on the side of the extended melting zone is the first to propagate in the tank, thus masking the more complex migration routes of the indicator and the correlation of the glass melt masses formed on two sides of the tank.

In the open mirror zone, both experiments demonstrated a significant difference in the speed of indicator migration compared to the melting zone up to the section between burners 3 and 4. This can be accounted for by the high glass melt temperatures on the side of the shorter melting zone.

A distinction in the maximum concentration of the indicator between two sides of the tank was registered only in the case of one-sided launching of the indicator, whereas general launching disguised such distinction.

A different mechanism of the propagation of the indicator along the tank sides under a distorted melting zone is clearly manifested in the differences in the overall duration of stay of the tagged glass melt on two sides of the tank in each considered section. Regardless of the indicator launching conditions, its stay in the tank is shorter on the side of the longer melting zone. Consequently, in the mode of averaging newly made melt in all sections along the tank, the displacement component on this particular side is present to a greater degree.

A distinctive feature of the circulation of single streams of fresh glass melt in wide sheet glass tanks, especially in the charging cycle, is the fact that the glass melted from the batch loaded through the lateral chargers arrives to this side of the tank within a short interval (1 – 4 h). The same melt appears on the opposite side of the furnace after circulation in the inner layers of the charging cycle, for instance, after 9 – 11 h, with the indicator concentration being significantly lower. This distinction suggests that the glass melt transfer to the opposite side of the tank is implemented by the bottom flows of the charging cycle, which provide for better glass melt averaging. Therefore, the glass melt defects related to the insufficient averaging conditions are located on the glass band mostly on the side from which an inferior-quality batch has been charged.

Thus, the main specifics of mass exchange of glass melt in wide melting tanks is strong lateral convection which leads to different mechanisms of glass melt circulation across the tank. In the sites affected by the lateral (near-wall) convection, the conditions for glass melt homogenization are better, compared to the melting tank zones along the longitudinal axis. Therefore, in the case of poor glass melt homogenization, the emergence of defects in the middle part of the glass bands being formed on top of metal melt becomes quite probable.

The obtained results are in good agreement with the data of earlier studies of sheet glass production carried out in

large-scale glass-melting tanks [1 – 5] and data on tank models.

In the present study, the indicator was launched with a relatively narrow front. This made it possible to study in greater detail the conditions of migration and homogenization of single flows and streams of glass melt across the tank, and to deepen our knowledge of the complicated general picture of glass melt circulation in glass-melting tanks.

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